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LANDFILL SITE SELECTION BY INTEGRATING ANALYTICAL HIERARCHY PROCESS AND GEOGRAPHIC INFORMATION SYSTEM

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Abstract: In solid waste management, landfilling is still widely practiced because it is convenient and consumer friendly. Unfortunately, many landfill sites have closed and cause problem in managing the waste. The purpose of this study is to suggest suitable and potential sites for landfill in Johor Bahru area through mapping technique and database system. Analytical Hierarchy Process (AHP) is a method for analysis and supports decision where multiple and competing objectives are involved. Fifteen parameters were identified to use in AHP process. In this method, the process is divided into hierarchy before pair wise comparison was done and the result is prioritizing according to their weightage. The process is continued with weightage evaluation and its consistency. Landfill site selection process involved many spatial data and strenuous in handling it. Geographic Information System (GIS) can give significant help because it can potentially handle large volume of data that need to be evaluated and processed. The method used in GIS is digitizing, buffering and overlays. As a result in AHP, the most important criterion is river weighted 0.149 of all criteria and the least important criteria are distance to main road weighted 0.028 of other criteria. In GIS method, there are six parameters selected which are main road, plantation, residential area, swamp, grassland and river coverage. The findings identified two potential sites for landfill area because it satisfied all given requirements. Integration of GIS and AHP is suitable to be used in landfill site selection process because it will helps in locating new landfill site that is environmentally, economically and socially wise.

Keywords: *Landfill, site selection, GIS, AHP*

1.0 Introduction

In the early 1970s, the density population of Malaysia was still low and waste management systems were not important because the waste produced mainly organic material. The quantities are low and the generators can handle by burning or burying the waste as well as feeding to domestic animals. The needs for the waste management are initiated in late 1970s when the development of housing schemes throughout the country that required local government and local municipalities to ensure the good sanitary and health conditions were provided for developed area.

This results in introduction of basic waste collection system, which involved solid waste produced being hauled from residential area to disposed at dumping ground owned by municipalities located in unwanted area and only a mere open dumps. These open dumps were small to cater for needs of population less than 10,000 people (Agamuthu and Fauziah, 2011). Since then, the waste generation has increased with expansion of population and the needs for larger disposal waste site become crucial and the old practice were unsustainable in the increasingly urban lifestyle. The primary method to disposed solid waste is by landfill. In Malaysia, the average solid waste disposed from January to March 2010 is 20,500 tonnes per day and in Johor; the amount solid waste disposed is 2,600 tonnes per day (National Solid Waste Management Department, 2010). Based on World Bank, 1999, the daily waste generation rate in urban area was about 760,000 tons and expected to sharply increase to 1.8 million tons per day by the year 2025.

The characteristics of solid waste are different according to its categories. It usually can be categorized into domestic or municipal, hazardous, clinical waste and scheduled waste. Municipal waste includes household waste, construction and demolition debris, sanitation residue and waste from street. With rising urbanization and change in lifestyle and food habits, the amount of municipal solid waste has been increasing rapidly and its composition changing. Industrial waste and industrial waste are group into hazardous waste because they may contain toxic substance that can give harmful effect. Hazardous wastes could be highly toxic to humans, animals, and plants, they are corrosive, highly inflammable, or explosive; and react when exposed to certain things such as gases. Household wastes that can be categorized as hazardous waste include old batteries, shoe polish, paint tins, old medicines, and medicine bottles (UNEP, 1999). Hospital waste or biomedical wastes are groups into clinical waste. It is generated during the diagnosis, treatment, or immunization of human beings or animals or in research activities in these fields or in the production or testing of biological. This includes cultures and stocks of infectious biological, human pathological waste, human blood and blood product, sharps that had been used or in contact with animal or human during treatment, and unused sharps including hypodermic needle and suture needle (Salkin, *et.al*, 2000). This waste is highly infectious and can be a serious threat to human health if not managed in a scientific and proper manner.

Scheduled waste is a waste that listed in the First Schedule in the Environmental Quality (Scheduled Wastes) Regulations. The First Schedule waste is divided into two parts. Part one is for scheduled waste from non-specific sources which includes mineral and oil contaminated wastes, contaminated soil, waste, debris or matter resulting from cleaning of scheduled waste, containers and bags containing hazardous residue and mixtures of scheduled waste. Part two is scheduled wastes from specific sources. Wastes that falls in this part is mineral oil and oil contaminated wastes, tar residue from oil refinery, wastes of printing ink, varnish or wood preservatives containing organic solvent, ashes from waste incinerators, latex effluent containing organic solvents, asbestos wastes, and waste from manufacturing of explosive. This scheduled waste need to be disposed and treated at prescribed premises or at on-site treatment facility (Malaysia, 1989).

There are three main methods of solid waste disposal which is composting, incineration and sanitary landfill but the oldest method of waste disposal practiced by man is landfilling. Landfill is recommended and acceptable method of solid waste disposal. But, it is often misunderstood with waste disposal in open dumps and burning. It is not open dump where salvage is permitted and usually exhibit undesirable characteristics of a dump: unsightly appearance, burning waste, blowing dust and paper, infestation by rodent, pollution of air and groundwater. Landfill is an engineering approach that needs detailed planning, careful construction and efficient management and operation. Types of waste to be landfill are municipal solid waste, mass waste, soil, waste water sludge and bulky waste. The life-cycle of landfill starts from planning, construction, operation, completed, and final storage phase. In general, solid wastes are spread in thin coverage, compacted to smallest particles volume and being covered by soil to minimize environmental pollution.Landfill has been controversial issue since past few decades. It is because as the country rapidly growing, the amount of waste generated daily increasing per year. In Malaysia, landfill is still the main method in waste disposal, therefore more space are needed to cover all the waste disposed. Unfortunately as developing country, the area or land for landfill site are insufficient to accommodate all the waste. Conventional method is still practiced in deciding suitable site and this method consumed more time. Usually, the decision will be made based on availability of the land.

The three main functions of a sanitary landfill system are storage and treatment, environmental protection and land development. In storage and treatment, the effective sanitary landfill must have capabilities in safely storing and containing the waste in its boundary and retained the leachate from seeping out to the environment. It also essential to prevent the waste from emitting unpleasant odour, leachate quantity be reduced and treated and gaseous emitted should be minimized. This function can be divided into three sub functions, which are retaining function, seepage control function and treatment function. Functions of sanitary landfill in environmental protection are important to minimize and avoid harmful effect to human health and to protect the surrounding environment. The harmful effects are caused by discharge of leachate for landfill, emission of volatile greenhouse gaseous, foul odour, vectors, noise pollution and disturbances. The third function of sanitary landfill is in land development. The post closure land use must be evaluated and decided thoroughly with consideration towards ground conditions, environmental conditions and surrounding conditions. Non-residential and low construction development such as recreational facilities should be limited when developing the post closure land. Additional ground stabilization and mitigation measures may be necessary before any construction and any development must be carefully evaluated. In a closed landfill site, the decomposition process continues and results in continuous emission of toxic gases, ground settlement and subsidence over period of time. Thus, all closed landfill site that not redevelops will continuous monitored to check out their conditions and environmental effects (Ministry of Housing and Local Government, 2004).These functions will ensure our world become a better place in terms of solid waste management.

There are few requirements in selection of new landfill site in order to satisfy all three main function of sanitary landfill. The requirements include planning principles for solid waste and toxic waste landfill site i.e. physical, geological, location and size, infrastructures facility, social and environment, land classification and transfer station.

The fundamental site selection criteria are safe structure from potential problems such as flooding and landslide assessed the impact of earth-moving equipment and significant traffic flow on neighbourhood and needed for additional facilities, effect on quality and quantity of surface water and groundwater (McBean *et al.*, 1995). In July 2007, Solid Waste and Public Cleansing Management Act of 2007 had been approved by the Parliament of Malaysia. The National Solid Waste Department and solid waste corporation were established under the Ministry of Housing and Local Government (MHLG) which is allow the Federal Government to manage solid waste and public cleansing from local council and state government. They were effectuating policy formulation, planning management of solid waste including financial management (Omar, 2008).

2.0 Materials and Methods

2.1 Materials

The materials used in this research are questionnaire forms and maps produced by Department of Survey and Mapping Malaysia (JUPEM). The map collected is hydrogeological map, geological map, seismotectonic map and topography map. The topography map used is map no. 4451, 4551, 4552, 4651, and 4652. The purpose of the questionnaire is to obtained data needed for AHP analysis.

2.2 Methodology

The flow chart of overall methodology used in this study as shown in Figure 1. In the first stage, problem statement and scope of study were identified. Comprehensive studies on past research related to this study are made to determine research gap from previous study, suitable methods to use and criterion needs to be considered in this study.

The most suitable method to be use in this research is GIS and AHP. Both of these methods were integrate to produce reliable and valid result. Data collection was done in two ways which is by questionnaire and gathering maps from parties concerned. In data analysis, both methods are done separately and finally, both results were combined to produce the recommended site for new landfill siting.

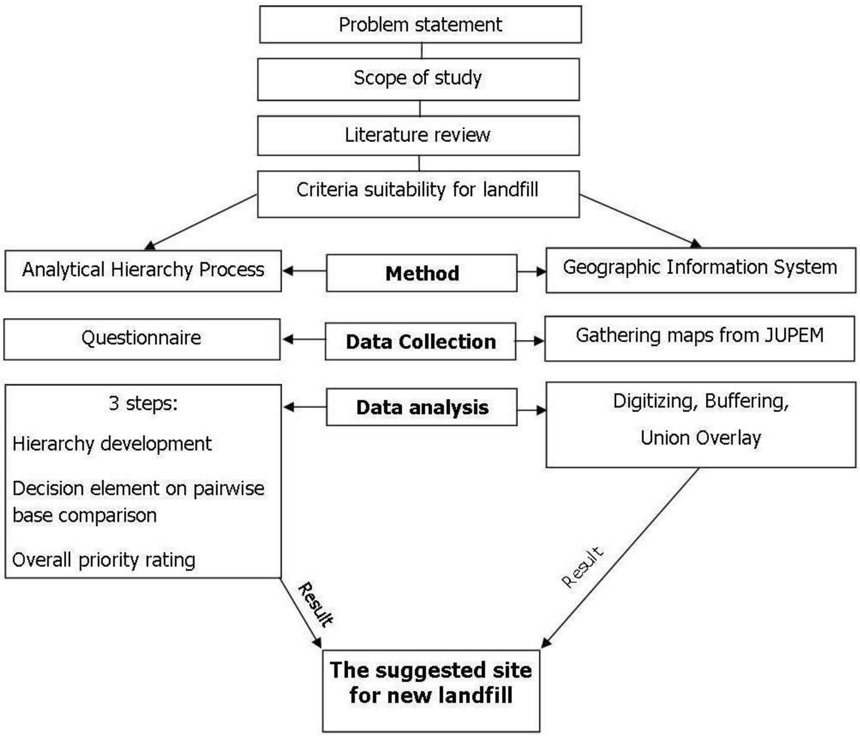

Figure 1: Flowchart of overall landfill site selection

Geographic Information System (GIS) is a system that can capture, store, collect, transform, analyse and display spatial data. With growth in the availability of digitized and spatial data, some GIS methods of site selection have become available (Ersoy and Bulut, 2009). GIS have capability to handle and simulate the necessary economic, environmental and political constraints (Naset.al, 2010) as they can play an important role as a decision support tool regarding optimum waste site selection (Babanet.al, 1998). The two main cartographic evaluation methods using GIS are constraint mapping and overlay mapping (Ersoy and Bulut, 2009). Land suitability analysis is a process to determine the most suitable and preferred area for subjective matters according to the inspected aspects. This process enquires a lot usage of the maps and data which by using GIS will effectively help in the analysis process. It is because, in GIS the data can overlay and most of the analysis can be done and the final powerful tools to display including the output maps.

Two process of GIS used in this research is buffering and union overlay. Buffering is a process to create area from calculated distance from the point, line or area of objects (DeMers, 2000). It is another method of reclassification because it is a polygon created at specific distance and based on location, shape and orientation of existing object. For point object, the buffer is where the limit is of specified radius around the point. For line object, the buffer is where the limit of specified perpendicular distance on both sides of the line and form a curve at each end. For polygon object, the buffer is a region where the limit is a specified perpendicular distance from the boundary of the polygon. Figure 2 shows the illustration of buffering technique. Union overlay is a process where two different coverage map is overlapped on each other to get new type of map. The illustration for union overlay as shown in Figure 3 below.

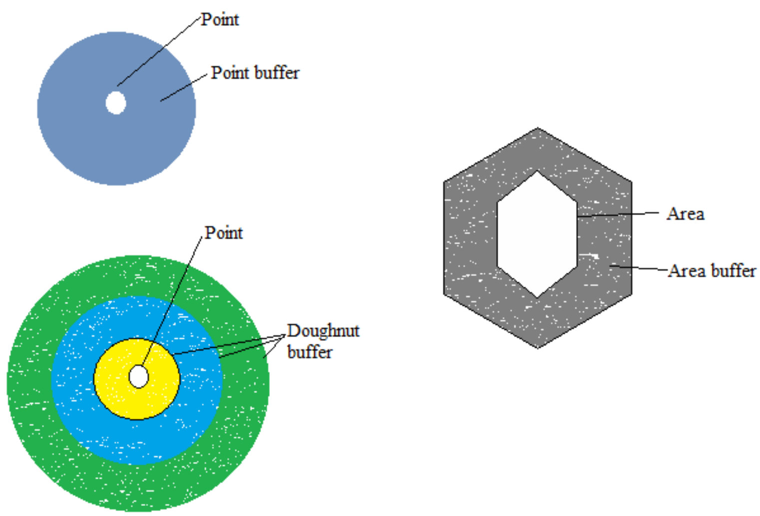

Figure 2: Point, doughnut and area buffer types (DeMers, 2000)

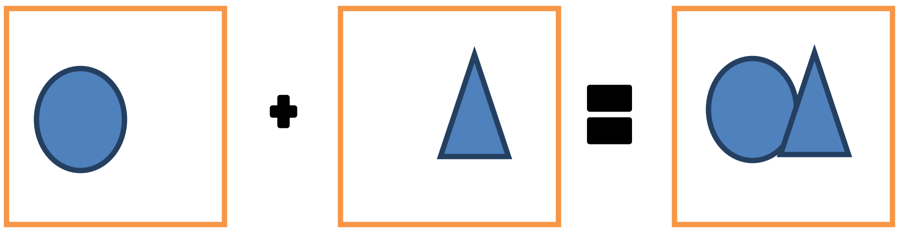

Figure 3: Illustration of union overlay

Analytical Hierarchy Process (AHP) is grouped into Multiple Criteria Decision Analysis (MCDA). AHP in its standard format also develop a linear additive model by using procedures for deriving the weights and the scores achieved by alternatives which are based on pairwise comparisons between criteria and between option, respectively (Department of Communities and Local Government, London, 2009). It is based on three principle namely; decomposition, comparative judgment, and synthesize of priorities. The decomposition principle needs the decision problem to be divided into a hierarchy that captures the important elements of the problem. The comparative judgment principle requires the assessment of pairwise comparisons of the elements within a given level of the hierarchical structure, with respect to their parent in next higher level. The principle of synthesis takes each of the derived ratio-scale local priorities in many levels of the hierarchy and constructs a composite set of priorities for the elements at the lowest level of the hierarchy.

From these principles, there are three main steps in AHP (Malczewski, 1999): The steps are developing the AHP hierarchy, comparing the decision elements on pair-wise base and constructing an overall priority rating. The hierarchical structure is as in Figure 4.

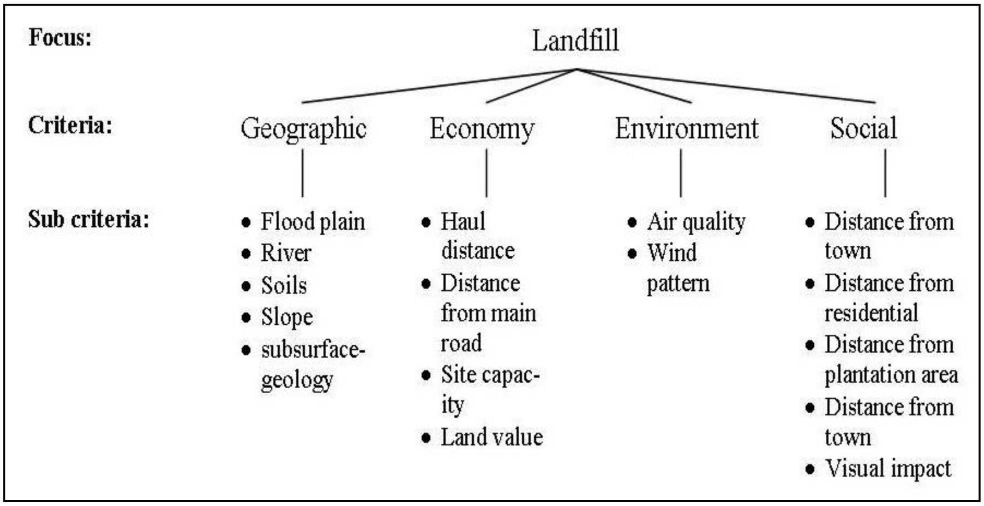

Figure 4: The developed hierarchy for landfill site selection

The implementation of GIS and MCDA in various fields in site selection has proved this method is suitable to be applied in solid waste management and will help decision making to improve this problem (Nas *et al.* 2010 and Gemitzi *et al.* 2007). MCDA is needed to helps decision maker manage the complex and substantial information in obtaining the landfill site. GIS will be the data storage for all information needed because of its ability to analysing spatial data from a variety of sources (Sener *et al.* 2011). It also has capability to handle and simulate the necessary economic, environmental, social, technical and political constraints (Nas *et al.* 2010). Thus, by using both GIS and MCDA, the system for landfill siting can be produce through mapping and database collection as shown in Figure 5.

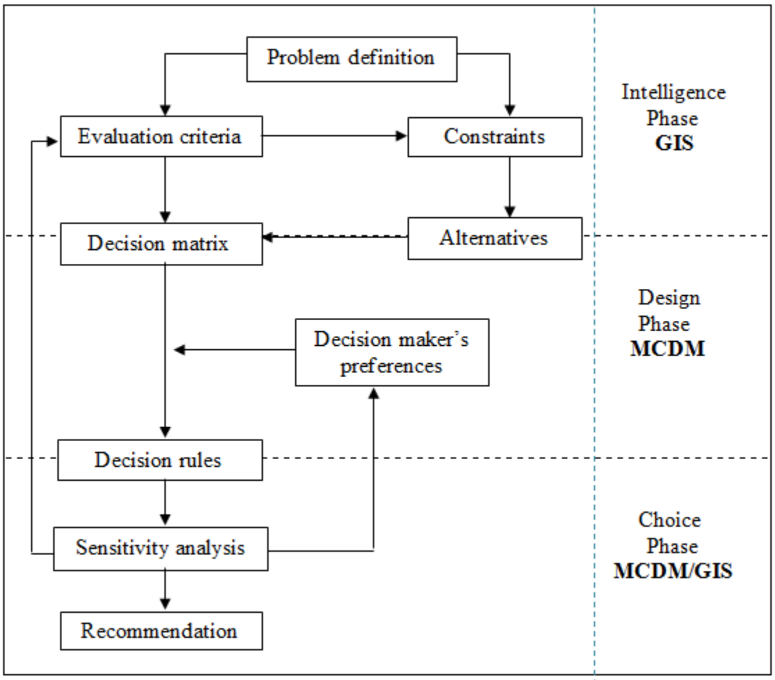

Figure 5: Framework for spatial multi criteria decision analysis (Malczewski, 1999)

3.0 Case Study: Johor Bahru

3.1 Background of Johor Bahru

Johor is one of the state developing at pace in Malaysia. This factor will contribute to the increasing amount of solid waste generated. Unfortunately in Johor, until 2010, 21 landfills have been terminated and the number of operating landfill only 13 sites and among them, one is sanitary landfill and others are non-sanitary landfill (National Solid Waste Management Department, 2012). This has causes great impacts on environment because the existing landfill could not accommodate the waste produced and this lead to other problem such as improper waste management, leachate leaking, and bad scenic view to the community. To overcome this problem, new landfill site are needed. But, it is a hard task as there are many criteria and parameters need to be consider in making decision to siting new landfill. This includes social, physical, economic, political, technical parameters and environmental aspects (Sener *et al*. 2011; Zamorano *et al*. 2008; Nas *et al*. 2010).

3.2 Result and Discussion

Two main result are discussed i.e. AHP and spatial analysis. In AHP analysis, result of comparison of pairwise (Figure 6) and overall priority rating (Table 1) are obtained. The criterion are arrange according to their weightage from the highest weightage to lowest weightage. Highest weightage indicates it is the most preferred compared to other criterion. The lowest weightage indicates it is the less preferred compared to other criteria. The total value for weightage must be 1.000 and 100% in terms of percentages for all criteria.

Landfill site suitability criterion

Pairwise Comparison Matrix

	Distance to reside	Distance to plar	Distance to mai	River	Site capacity	Soil permeabilit	Visual effect	Land value	Distance to tow	Groundwater lev	Air quality	Flood plain	Haul distance	Slope	Subsurface geology
Distance to residential	1	3	3	1	1	2	2	3	2	1	2	3	2	3	1
Distance to plantation	1/3	1	1	1/4	1/3	1/3	1	1	1/2	1/3	1/3	1/2	1/3	1/2	1/4
Distance to main road	1/3	1	1	1/4	1/3	1/3	1/2	1	1/2	1/3	1/2	1/2	1/3	1/2	1/3
River	1	4	4	1	2	3	3	4	4	2	3	3	2	3	2
Site capacity	1	3	3	1/2	1	1	1/2	1/3	1/2	1	1/3	1/3	1/2	1/3	1
Soil permeability	1/2	3	3	1/3	1	1	2	4	3	1	3	2	2	2	1
Visual effect	1/2	1	2	1/3	2	1/2	1	2	2	2	2	2	1	2	1/2
Land value	1/3	1	1	1/4	3	1/4	1/2	1	1/2	1/3	1/2	1/2	1/2	1/2	1/3
Distance to town	1/2	2	2	1/4	2	1/3	1/2	2	1	1	1	1	1/2	1	1
Groundwater level	1	3	3	1/2	1	1	1/2	3	1	1	2	2	2	2	1
Air quality	1/2	3	2	1/3	3	1/3	1/2	2	1	1/2	1	1	1/2	1	1/2
Flood plain	1/3	2	2	1/3	3	1/2	1/2	2	1	1/2	1	1	1/2	1/3	1/2
Haul distance	1/2	3	3	1/2	2	1/2	1	2	2	1/2	2	2	1	2	1/2
Slope	1/3	2	2	1/3	3	1/2	1/2	2	1	1/2	1	3	1/2	1	1/3
Subsurface geology	1	4	3	1/2	1	1	2	3	1	1	2	2	2	3	1

Figure 6: Pairwise comparison matrixes for the criterion

Table 1: Overall priority rating

No.	*Criterion/Parameters*	*Weightage*	*Percentage (%)*
1.	River and swamp	0.149	14.9
2.	Distance to residential	0.112	11.2
3.	Subsurface geology	0.090	9.0
4.	Soil permeability	0.086	8.6
5.	Groundwater level	0.081	8.1
6.	Visual effect	0.069	6.9
7.	Haul distance	0.066	6.6
8.	Site capacity	0.060	6.0
9.	Distance to town	0.051	5.1
10.	Slope	0.050	5.0
11.	Air quality	0.049	4.9
12.	Flood plain	0.046	4.6
13.	Land value	0.034	3.4
14.	Distance to plantation	0.029	2.9
15.	Distance to main road	0.028	2.8
	Total	*1.000*	*100 %*

In spatial analysis, three main results are obtained i.e. digitizing coverage maps, buffering coverages and final landfill site suitability map. The topography maps are digitized in AutoCAD and then converted to polyline and polygon coverage in ArcGIS. In buffering process, the digitized coverages are buffer according to the requirements in guidelines and analysis of previous studies. After buffering all the coverages, overlay process were done. The overlays are done according to priorities level that has been described in Table 1. In first overlay, the selected coverages are river and swamp overlay with residential coverages. Then, the overlay coverage of river and residential is overlay with plantation coverage with grassland and finally with road coverage. During the overlay process, it is obvious that the less parameter are used, the result will be less accurate compared when using more parameters. The accuracy is important to ensure new location of the landfill will satisfy the guideline of landfill site.

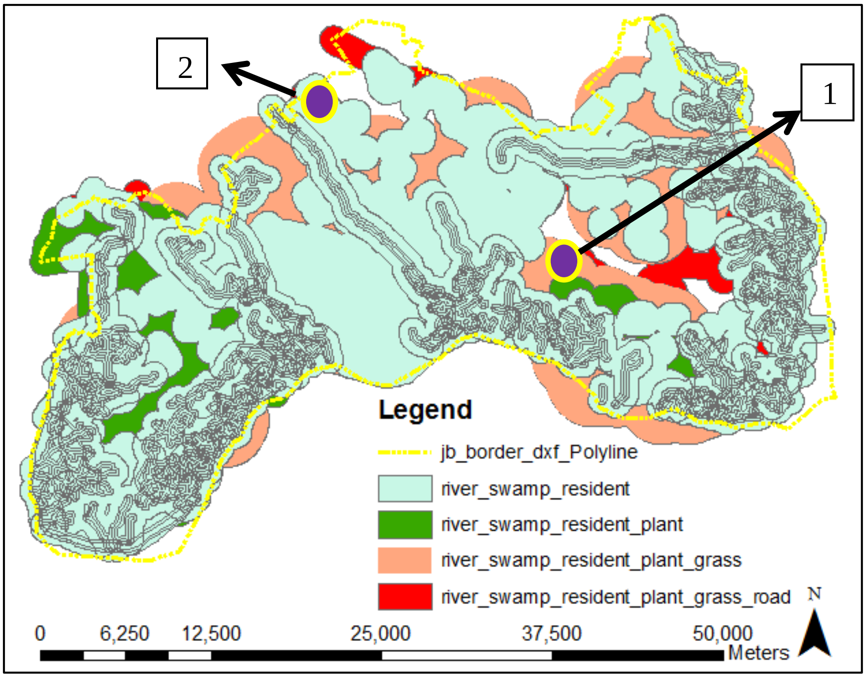

Figure 7: Overlay of river, residential, plantation, grassland and road coverages

Figure 7 shows the overlay of all coverage which involved all spatial data needed including river, residential, plantation, grassland and main road coverages. The suitable site for new landfill site is marked by purple circle (white area). White area indicates the area is not in buffering zone and suitable for landfill site. There are two potential location have been identified labelled with number one and two. These two locations are chosen because it is not within the buffering area and far from the river, the most preferred criteria in the AHP analysis. These two locations are also the largest area compared to other white area. This size is important to ensure further development and infrastructures can be built in future to the landfill site and also to reduced cost in finding new landfill in longer time. From this map, it is proved that having sufficient spatial data is important in site suitability process to ensure its accuracy in prediction process.

4.0 Conclusions

In nutshells, two suitable sites for landfill can be located using integration of AHP and GIS method as discussed above. But, this recommended site can be future enhanced by collecting other data such as land price to ensure the recommended site more accurate and more economic. The benefit of this study is it helps the stakeholders to determine the new landfill site in the future by saving cost and time. Using this method, it can conserve the environment and the surrounding area.

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